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AN ABSTRACT OF THE THESIS OF Daniel D. Sullivan for the Master of Arts in Anthropology presented May 15, 1986.

Title: Neutron Activation Analysis and Chemical Inference for the Identification of Buena Vista Ceramics.

APPROVED BY THE MEMBERS OF THE THESIS COMMITTEE:

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Daniel J. Scheans, Chairman

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M. Ann Bennett

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Marvin H. Beeson

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Kenneth M. Ames

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Dennis W. Barnum

Instrumental Neutron Activation Analysis was used for this study of stonewares collected from the site of the Buena Vista/Oregon Pottery Company (1866-1890).

The results show significant chemical signatures in the samples tested. Thorium/ytterbium and thorium/chromium ratios within their respective ranges of variation demonstrate a relative conformity among all samples of Buena Vista ceramics.

NEUTRON ACTIVATION ANALYSIS AND CHEMICAL INFERENCE FOR THE IDENTIFICATION OF BUENA VISTA CERAMICS

by

DANIEL D. SULLIVAN

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF ARTS
in
ANTHROPOLOGY

Portland State University

1986

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of Daniel D. Sullivan presented May 15, 1986.

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CHAPTER I

INTRODUCTION

The principle objective of this study is to determine the existence of chemical conformities in the clay(s) used for the manufacture of Buena Vista ceramics that may differ from those in similar ceramics from the same historic period. Buena Vista ceramics have been described in a preliminary study by Scheans (1984). His study is focused on stylistic and technological attributes found in ceramic sherds which were surface collected and excavated from a waster dump at the site of the Buena Vista/Oregon Pottery Company and compared to whole pieces from private collections. Scheans' analysis has established a typology for and characterized the process of manufacture of Buena Vista stonewares. Differences in style and technology have raised questions about the continuity of the material used for production of these ceramics both in time and location. Therefore, underlying this study is the need to improve the precision of inference and, thereby, future historical, archaeological, and anthropological interpretations of Buena Vista ceramics and others unique to the historical cultural development of the Pacific Northwest.

Clay, being a material specific to its geological origins and various weathering processes, is a configuration of recognizable proportions of chemical elements and conditions leading to deposition. Given a relatively uniform environment for manufacture (e.g., kiln

temperature, addition of temper, etc.), the products of a specific pottery (e.g., the Buena Vista Pottery Company) should reflect a chemical composition for the most part unchanged from that of the clay(s) used in the process. Using appropriate analytical methods permits (1) the determination of any conformity among samples and, (2) validation of the clay source(s) and its associated manufacturing provenience. Instrumental Neutron Activation Analysis (INAA) is a method for quantitative elemental analysis. The data derived from INAA can produce meaningful results not only on its own merits, but also (1) enhance the credibility of inferences made through other types of analysis and, (2) raise further research objectives.

> Chemical compositional studies are in flux and mistakes are being made, but instrumetnal analytical techniques are sensitive, statistical methods are powerful, and effective characterization of pottery is more than a gleam in the eye of the analyst. In evaluating this approach, we especially note the potential of workshop debris (kiln wasters) in establishing local reference groups... As in much archaeolgoical research, ceramic compositional analysis takes place the interface of the natural environment with the social and cultural components of production. With modest improvement in our present body of methods and more judicious use of available techniques, we should soon be able to examine nuances of these relationships (Bishop, Rands and Holley 1982:318, 320).

QUANTIFICATION

Beyond statistical methods embedded in the computer programs required for the derivation of data in this study, elaborate statistical presentations will not be made. Rather, derived data will be displayed in tabular form, and data with inferential merit will be displayed graphically and in bivariate plots. Samples used in this study are not representative of a statistical population. Rather, they were selected

for INAA on the basis of attributes illustrating a transect of style and technology found in diagnostic sherds from Scheans' (1984) study assemblage. Two questions are considered here: (1) Are any of the variations in style and technology in the assemblage the result of intrusive ceramics? and/or, (2) Are any variations in style and technology in the assemblage a record of historical development at the site?

HISTORY

The site of the Buena Vista Pottery Company is located in Polk County, Oregon, just south of the town of Independence and a short distance from the left bank of the Willamette River. The pottery produced stonewares between 1866 and 1890 under the proprietorship of Freeman Smith and his son Amedee. The name was changed to the Oregon Pottery Company in 1888 (Scheans 1984:50). Archaeology students and volunteers made surface collections and one excavation at the site between 1981 and 1983. Diagnostic ceramic sherds were classified and catalogued at the Ceramic Analysis Laboratory at Portland State University where they are currently curated. Although the pottery produced a variety of products, this study is restricted to the three classes of vessels described by Scheans. These include slip glazed, salt glazed, and unglazed wares. Any taxonomic reference in the current study is consistent with the paradigms established within these classes.

CHAPTER II

EXPERIMENTAL PROCEDURE

SAMPLES

A total of 32 samples were used for INAA in this study. Twenty-seven of these samples were obtained from surface collections and one excavation at the Buena Vista site and selected from Scheans' (1984) study assemblage. The remaining five samples were from sherds known to be products of the Palouse Pottery Company, Washington, and selected from the Ceramic Analysis Laboratory collection at Portland State University. The Palouse samples represent the control group in this analysis. A summary of all samples appears in Table I.

PREPARATION

All samples were washed in tap water, dried, and crushed to a coarse powder with a stainless steel mortar and pestle. As indicated in Table I, selected samples were prepared with part of all glaze(s) removed to determine if proportions of elements within the clay bodies of the sherds would be significantly skewed by possibly different element proportions in the glazes. The remaining samples were prepared with glaze intact, or without, as in the case of bisquit wares. Between 0.9515 gm and 1.4679 gm of powder was weighed into 0.5 dram polyethylene sample vials which were then sealed and labeled.

TABLE I

BUENA VISTA AND PALOUSE POTTERY COMPANY
NEUTRON ACTIVATION ANALYSIS SAMPLES

	Sample Number	Artifact Number	Formal Description	Remarks
Buena Vista Salt Glazed Wares (Interior Albany Slip Glazed)	BV-1	BV813	rim, pot	all glaze removed
	BV-2	BV816	rim, pot	all glaze removed
	BV-3	BV239	rim, pot	all glaze removed
	BV-4	BV1569	rim, pot	all glaze removed
	BV-5	BV809/811	rim, pot	all glaze removed
	BV-6	BV813	body	Albany glaze removed
	BV-7	BV813	body	salt glaze removed
	BV-8	BV809/811	body	
	BV-9	BV011	body	all glaze removed
	BV-10	BV015	body	all glaze removed
	BV-11	BV057/058/059	body	cobalt motif
	BV-13	none	body	from BV3/Square CM, 12-18" below surface
Buena Vista Albany Slip Glazed Wares (Exterior and Interior Glazed)	BV-14	BV689	rim, churn	
	BV-15	BV289	rim, bowl	
	BV-16	BV680	base, jar	
	BV-17	BV948/952	section, bowl	salt glazed rim
	BV-18	BV485	cover	
	BV-20	BV895	cover	black glazed impressed floral motif, no interior glaze
	BV-21	BV677	cover	brown glazed impressed floral motif, no interior glaze
	BV-22	BV485	body	
	BV-24	BV895	body	
	BV-25	BV948/952	body	
Buena Vista Bisquit Wares	BV-26	BV713	cover, churn	
	BV-27	BV1707	rim, pot	
	BV-28	BV567	rim, pot	
	BV-29	BV961	rim, pan	
	BV-31	BV1048	rim, jar	
Palouse Salt Glazed Wares (Interior Albany Slip Glazed)	BV-51	none	body	cobalt motif
	BV-52	none	body	cobalt motif, Albany glaze removed
	BV-53	none	body	cobalt motif, salt glaze removed
	BV-56	none	base	
	BV-58	none	base	salt glaze removed

Unless noted, samples were prepared without removal of glaze(s). Palouse samples are from site 45-WF-133 and were collected by Idaho State University.

IRRADIATION AND ASSAY

The sealed vials were irradiated using the TRIGA MARK I, 250 kW thermal neutron reactor at Reed College in Portland, Oregon. The samples were co-irradiated with a sample of United States Geological Survey (USGS) standard diabase W-1 (Flanagan 1976) as a standard for all elements reported in this study. Exposure was for one hour at 225 kW with a flux of $1.8X10^{12} n/cm^2$ sec.

Activities of the irradiated samples were measured using facilities of the Geology Department at Portland State University. Assay of the samples was conducted between four and one-half days and ten days after irradiation using a germanium-lithium high resolution detector coupled to a Tracor Northern 4000-channel pulse height analyzer and a floppy disk data recorder. Detection time was 1,000 seconds for all samples. A description of the neutron activation program and procedures can be found in McMillan (1978).

Data from floppy disks were hard-copied, recompiled, and tabulated according to selected elements and their respective half-lives in days, and gamma ray energies in keV as shown in Table II.

After formatting, all relevant data were then analyzed using a FORTRAN computer program which:

> ... reduces Instrumental Neutron Activation Analysis data to element abundances by comparing samples to a known concentration in a standard. It also computes relative errors based on counting statistics (Beeson and Keedy 1968).

This program appears in the Appendix.

TABLE II

CHARACTERISTICS OF SELECTED ELEMENTS
IN BUENA VISTA AND PALOUSE
CERAMICS

Element	Determined From	Half-Life (Days)*	Gamma Ray Energies (keV)*
Samarium	^{153}Sm	1.950	103.2
Lutetium	^{177}Lu	6.796	208.4
Ytterbium	^{175}Yb	4.196	282.5 396.3
Thorium	^{233}Pa	27.000	311.9
Chromium	^{51}Cr	27.720	320.1
Lanthanum	^{140}La	1.678	328.8 487.0 815.8 1,596.2
Scandium	^{46}Sc	83.800	889.3 1,120.5
Iron**	^{59}Fe	44.600	1,099.2
Cobalt	^{60}Co	1,925.000	1,332.5
Sodium***	^{24}Na	0.625	1,368.6

* From McMillan (1978) except for ^{233}Pa and ^{51}Cr, which are from Filby, et al. (1970).

** Fe as FeO

*** Na as Na_2O

SELECTION OF ELEMENTS

With the exception of cobalt (Co), criteria for selection of elements after analysis was the co-occurrence of the same elements in all samples as prescribed by the standard used for the assay. Cobalt was included, even though it did not fully meet this criteria, because of its occurrence as a colorant in underglazes on some of the samples (see Table I).

Included in the selection process was a consideration of decreases in concentrations of elements in the clay(s) as a function of kiln firing temperatures. Rye (1981:49), reporting on the work of Attas, Yaffe, and Fossey (1977), notes that samarium (Sm), lutetium (Lu), thorium (Th), and chromium (Cr), as well as other elements (which are insignificant to this study), show decreases in concentration after firing. Differences in temperature from one firing to another, and/or a single firing depending on location within the kiln itself could contribute to the overall variability of certain elemental concentrations in clay(s) after firing. Only when sherds are being compared to clay(s) would this be of significance; and then, with temperatures determined to be in excess of 700°C, correction factors should be applied (1981:49). Stonewares are traditionally fired at kiln temperatures of between approximately 1200°C and 1300°C (Nelson 1971:141, 311). Since this study compares sherds to sherds (all of which have been technologically identified as stonewares) deviations in the concentrations of the selected elements which are sensitive to firing temperature are, at least in part, relative to kiln temperature firing

range. Subsequently, these deviations may be reflected as a part of the range of variation in the data.

CHAPTER III

RESULTS

Results of the analysis for selected elements are presented in Table III. Iron (Fe) and sodium (Na) are reported by convention as oxides. Ferrous oxide (FeO) and sodium oxide (Na_2O) may or may not have been resident in the samples from the perspective of INAA (Beeson 1986). It is worth noting, however, that FeO and Na_2O are commonly-occurring oxides in ceramic chemistry and are represented for Fe and Na in this study as a reference for variability between samples. FeO remains unchanged in the firing process, while Na_2O is the combustion product of sodium carbonate (Na_2CO_3) with the loss of carbon dioxide (CO_2) (Nelson 1971:306 and Rye 1981:49). An examination of Table III shows a relative range of uniformity among all samples for Fe and Na.

As previously mentioned, Co was included because of its occurrence as a colorant in several samples. A brief comparison of the descriptions of samples in Table I to the data in Table II reveals that no apparent relationship exists in the assay as to whether Co could be visually identified and if so, whether or not it was mechanically removed.

Of the remaining elements in Table III, Th is the only element identified which clearly distinguishes the stonewares of the Buena Vista Pottery Company from those of the Palouse Pottery Company in the samples (see Table I). On this premise, Th was used as the ordinate

TABLE III

MEAN ELEMENT CONCENTRATIONS IN CERAMIC SAMPLES

Sample Number	Sm		Lu		Yb		Th		Cr		La		Sc		FeO		Co		Na_2O	
BV-1	20.50	0.20	0.97	0.17	5.80	0.90	15.00	4.00	106.00	15.00	97.00	3.00	19.50	0.30	2.30	0.20	15.00	3.00	0.74	0.
BV-2	12.97	0.15	0.88	0.15	5.20	0.80	11.00	3.00	83.00	11.00	63.10	1.90	16.39	0.20	1.80	0.20	11.00	2.00	0.62	0.
BV-3	30.10	0.30	1.12	0.18	6.70	1.00	12.00	4.00	84.00	11.00	108.00	3.00	12.77	0.17	1.66	0.15	0.	0.	0.38	0.
BV-4	18.70	0.20	0.73	0.13	4.60	0.70	13.00	4.00	80.00	10.00	84.00	2.00	15.97	0.18	1.84	0.14	0.	0.	0.35	0.
BV-5	15.64	0.18	0.86	0.15	4.90	0.80	13.00	4.00	95.00	12.00	74.00	2.00	17.00	0.20	1.71	0.18	12.00	3.00	0.67	0.
BV-6	18.60	0.20	0.86	0.15	5.10	0.80	13.00	4.00	88.00	13.00	89.00	3.00	17.80	0.20	2.20	0.20	0.	0.	0.84	0.
BV-7	17.60	0.20	0.78	0.14	4.80	0.80	13.00	4.00	83.00	12.00	84.00	2.00	17.00	0.20	2.42	0.19	0.	0.	0.64	0.
BV-8	15.71	0.18	0.89	0.15	5.20	0.80	14.00	4.00	75.00	12.00	75.00	2.00	17.20	0.20	2.09	0.18	14.00	3.00	0.72	0.
BV-9	14.71	0.18	1.10	0.18	5.30	0.80	14.00	4.00	86.00	12.00	71.00	2.00	18.00	0.20	1.89	0.19	10.00	3.00	0.70	0.
BV-10	15.23	0.18	0.97	0.17	5.30	0.90	14.00	4.00	79.00	13.00	74.00	2.00	16.80	0.20	2.10	0.20	14.00	3.00	0.84	0.
BV-11	21.60	0.20	1.12	0.19	6.20	1.00	12.00	3.00	89.00	12.00	99.00	3.00	16.10	0.20	1.78	0.18	11.00	3.00	0.80	0.
BV-13	13.90	0.16	0.75	0.13	4.40	0.60	12.00	3.00	83.00	11.00	64.90	1.90	15.68	0.19	1.93	0.16	13.00	2.00	0.72	0.
BV-14	13.39	0.16	0.80	0.14	4.30	0.70	12.00	3.00	103.00	12.00	58.10	1.70	19.80	0.20	2.62	0.17	11.00	2.00	0.64	0.
BV-15	13.35	0.16	0.75	0.13	4.00	0.70	12.00	3.00	93.00	12.00	60.60	1.80	18.40	0.20	2.24	0.17	0.	0.	0.68	0.
BV-16	13.20	0.15	0.79	0.13	4.20	0.70	11.00	3.00	94.00	11.00	57.20	1.70	19.50	0.20	2.54	0.16	12.00	2.00	0.64	0.
BV-17	15.32	0.17	0.94	0.16	5.10	0.80	14.00	4.00	86.00	11.00	73.00	2.00	15.14	0.20	2.09	0.13	10.00	2.00	0.25	0.
BV-18	18.20	0.20	0.90	0.15	5.10	0.80	13.00	4.00	102.00	13.00	85.00	3.00	17.40	0.20	2.23	0.17	18.00	3.00	0.53	0.
BV-20	8.97	0.11	0.52	0.09	2.40	0.40	11.00	3.00	65.00	9.00	44.00	1.30	17.10	0.20	3.46	0.16	9.00	2.00	0.42	0.
BV-21	10.21	0.12	0.49	0.09	3.20	0.50	11.00	3.00	69.00	10.00	49.50	1.50	18.40	0.20	2.70	0.14	9.20	2.00	0.31	0.
BV-22	17.44	0.20	0.82	0.14	4.70	0.80	12.00	3.00	86.00	12.00	81.00	2.00	16.90	0.20	2.14	0.16	10.00	2.00	0.53	0.
BV-24	9.55	0.12	0.55	0.10	2.80	0.50	12.00	3.00	75.00	10.00	47.80	1.40	17.90	0.20	3.56	0.16	14.00	2.00	1.20	0.01
BV-25	14.78	0.17	0.94	0.16	5.10	0.80	13.00	4.00	94.00	11.00	71.00	2.00	14.94	0.18	2.21	0.12	6.80	1.80	0.26	0.
BV-26	14.71	0.17	0.88	0.15	5.10	0.80	14.00	4.00	90.00	10.00	62.60	1.80	17.05	0.19	2.16	0.13	10.20	1.80	0.53	0.
BV-27	15.70	0.20	1.08	0.18	6.00	0.90	14.00	4.00	94.00	9.00	65.00	2.00	17.50	0.20	1.88	0.08	10.00	1.00	0.58	0.08
BV-28	18.90	0.20	0.93	0.16	5.60	0.90	14.00	4.00	96.00	11.00	78.00	2.00	17.40	0.20	1.89	0.13	0.	0.	0.49	0.
BV-29	6.91	0.09	0.40	0.07	2.30	0.40	11.00	3.00	85.00	9.00	35.00	1.10	17.28	0.20	3.80	0.13	13.10	1.40	0.18	0.
BV-31	13.28	0.16	0.82	0.14	4.80	0.80	12.00	4.00	89.00	10.00	56.50	1.70	16.77	0.19	2.16	0.12	14.30	1.80	0.55	0.
BV-51	9.82	0.12	0.57	0.10	2.70	0.50	21.00	6.00	57.00	8.00	49.80	1.50	18.20	0.20	1.95	0.11	16.60	1.80	0.46	0.
BV-52	12.22	0.15	0.61	0.11	3.10	0.50	25.00	7.00	68.00	10.00	60.10	1.80	22.90	0.30	2.47	0.15	22.00	3.00	0.61	0.01
BV-53	9.73	0.12	0.49	0.09	2.30	0.40	21.00	6.00	59.00	8.00	48.60	1.50	18.10	0.20	2.02	0.12	14.00	1.80	0.51	0.01
BV-56	11.49	0.13	0.45	0.08	2.40	0.40	25.00	7.00	53.00	7.00	60.80	1.80	20.50	0.20	1.80	0.09	13.60	1.60	0.11	0.
BV-58	11.78	0.14	0.48	0.09	2.40	0.40	26.00	7.00	63.00	8.00	62.20	1.80	20.90	0.20	1.77	0.10	10.90	1.60	0.12	0.

Standard error, based on the total number of detected gamma rays for each sample, follows to the right of each mean for each element which is reported in the same units as the concentration. All values are in parts per million (ppm), except for FeO and Na_2O, which are expressed in percent (%). The standard error for Na_2O is less than 0.005% unless otherwise noted. Values reported as 0.0 ppm for Co are below the detection limit defined as a calculated concentration less than three times the standard error. For Co, this is approximately 7.0 ppm.

for a number of trial bivariate plots against other selected elements. Ratios of inferential merit were determined to be those of Th with ytterbium (Yb) and Th with Cr. These ratios are presented in Figure 1 (Th/Yb) and Figure 2 (Th/Cr).

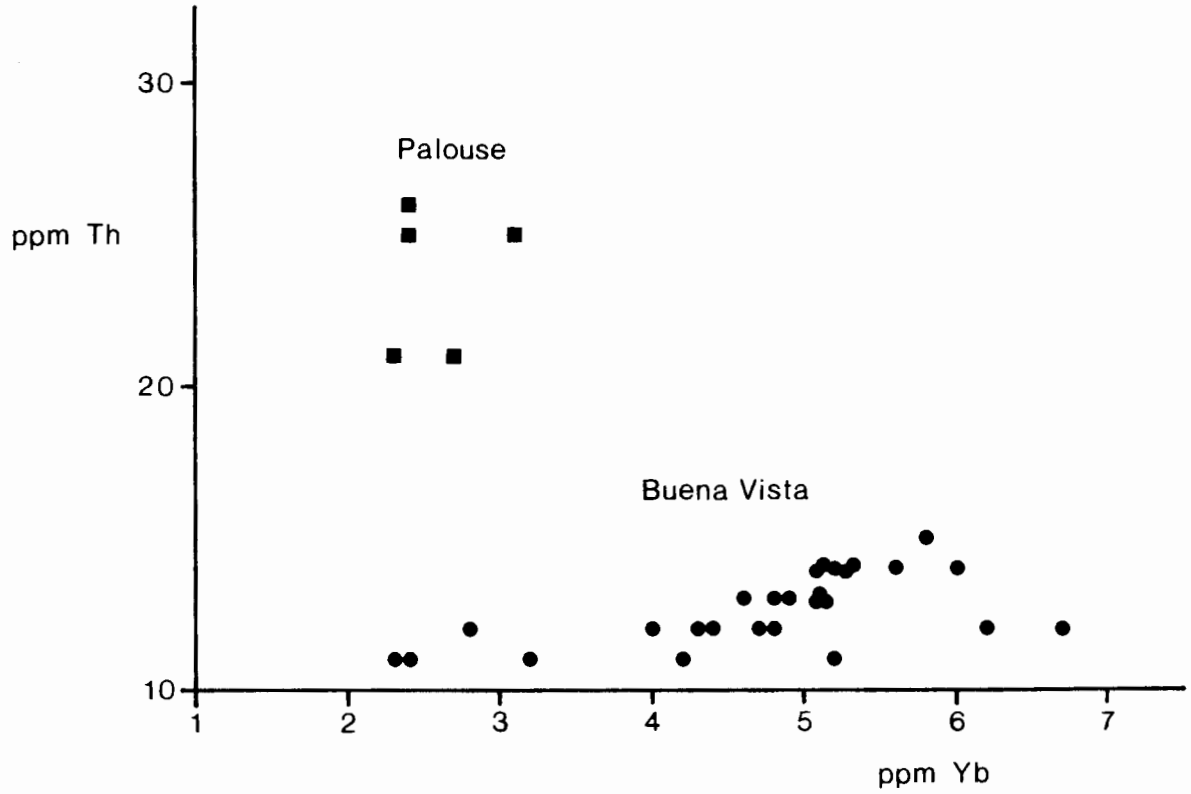

Figure 1. Scattergram of Th/Yb ratios for Buena Vista and Palouse ceramic samples.

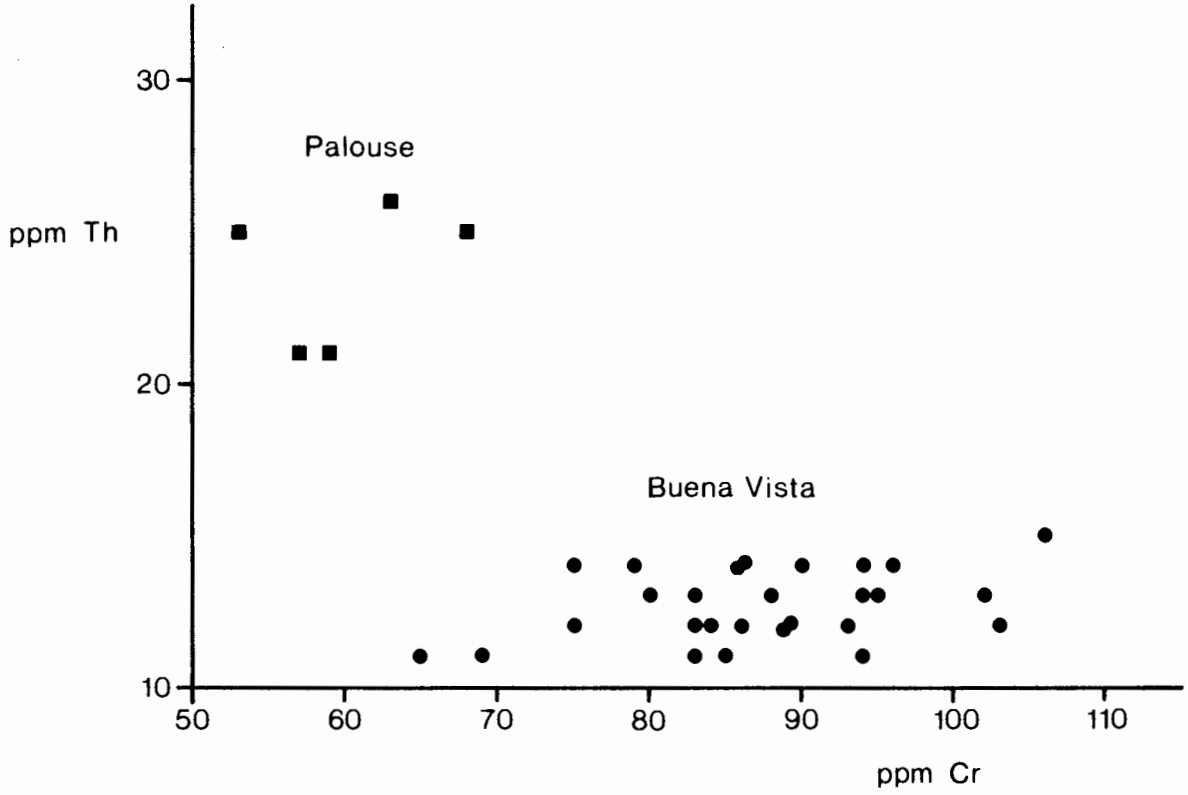

Figure 2. Scattergram of Th/Cr ratios for Buena Vista and Palouse ceramic samples.

CHAPTER IV

DISCUSSION

Th/Yb AND Th/Cr RATIOS

Inferential chemical signatures for Buena Vista ceramics are reported in the Th/Yb and Th/Cr ratios (Figures 1 and 2) for two reasons: (1) They best illustrate a clear demarcation between the Palouse control group and the Buena Vista samples compared to all other ratios of selected elements and, (2) they confirm along with technological support a subgroup within the Buena Vista cluster itself.

In review of Table I, it will be seen that sample numbers BV-20, BV-21, and BV-24 consist of black and brown glazed covers with impressed floral motifs. For Buena Vista ceramics, these three samples appear distinctively to the left of the cluster in their Th/Yb ratios (Figure 1) and are represented by the three plots in the lower left of their Th/Cr ratios (Figure 2). Although, as will be discussed, consideration was given to other variables which might contribute to the generation of subgroups within the Buena Vista cluster, this subgroup is distinguished primarily by impressed floral motifs.

CHEMICAL VARIABILITY

Several explanations can be given for possible variability in the chemistry of clays and glazes used in the manufacture of ceramics.

These include different temper-to-clay ratios, incomplete mixing, uneven distribution of minerals such as large inclusions of one or more minerals, and firing temperature relative to volatilization and combustion of certain elements. Also, variations in clay sources, such as from flood plains or agricultural land, which may vary annually can influence chemical signatures in the products of a pottery (Rye 1981:47-49).

Some samples in this study were specifically prepared to determine if glaze chemistry would significantly skew the results of analysis. The following groups are inclusive of samples taken from the same sherd with, or without, glaze removed and reported as prepared: (1) BV-1, no glaze; BV-6, salt glaze; BV-7, Albany glaze; (2) BV-5, no glaze; BV-8, salt and Albany glaze; (3) BV-17, salt and Albany glaze; BV-25, Albany glaze; (4) BV-18, Albany glaze; BV-22, Albany glaze; (5) BV-20, Albany glaze; BV-24, Albany glaze; (6) BV-51, Albany and salt glaze with cobalt underglaze motif; BV-52, salt glaze with cobalt underglaze motif; BV-53, Albany glaze and cobalt underglaze motif; (7) BV-56, salt and Albany glaze; BV-58, Albany glaze (see Table I).

Assessment of the data as reported in the Th/Yb and Th/Cr ratios (Figures 1 and 2) and in the range of variation for all selected elements as presented in Figure 3 suggests that glaze chemistry had no significant effect on the concentrations of elements in samples of the above groups or on the analysis as a whole. Although glaze chemistry may contribute to the overall picture of chemical variability among samples in this study, variables previously mentioned must be given the

weight of consideration. At present it is not possible to attribute any causality in this arena of chemical variability.

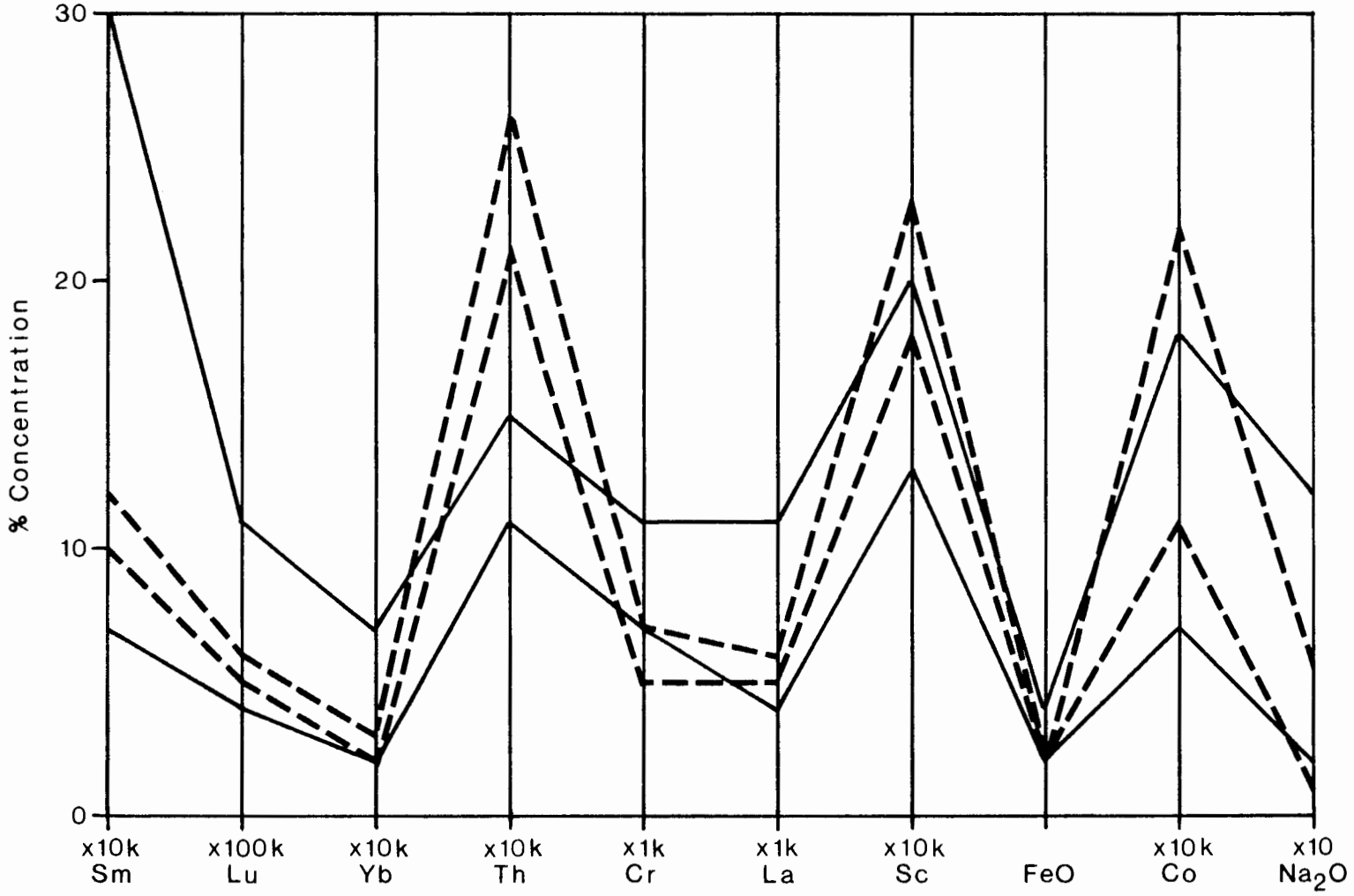

Figure 3. Comparison of the concentration ranges of selected elements for Buena Vista (solid lines) and Palouse (dashed lines) ceramics. Values have been rounded to their nearest whole percent (k = 1,000).

CHAPTER V

CONCLUSIONS

The Th/Yb and Th/Cr ratios in the samples tested demonstrate significant chemical signatures for the identification of Buena Vista ceramics. This conformity among samples serves further to validate the typological and processual schemata arrived at by Scheans (1984) with regard to a manufacturing provenience and its implied clay source(s).

With the possible exception of the floral impressed covers discussed in the previous chapter, variations in style and technology do not appear at this time to be a result of intrusive ceramics. Rather, this variation is most likely representative of historical development and/or idiosyncratic production.

Scheans (1984:4) has suggested that the floral impressed covers may be intrusive. If this is the case, these covers were probably manufactured using a clay source(s) located very near that used by the Buena Vista Pottery Company. The chemical subgroup of the cover samples is not that far removed from the Buena Vista cluster as a whole and is certainly within the range of variation found in the bivariate plots of other Buena Vista samples in their Th/Yb and Th/Cr ratios (see Figures 1 and 2). Possibilities which might explain the position of this subgroup, yet remain consistent with a singular manufacturing provenience, include different temper-to-clay ratios, perhaps for

increased durability, and historical accident, as in the use of clays from active floodplains or agricultural lands nearby.

The chemistry of salt and Albany slip glazes as well as cobalt underglazes used on Buena Vista and Palouse samples appears to have had little or no effect on the overall analysis of ceramics in this study.

Considering the statistical limitations set by the number of samples of Buena Vista and Palouse ceramics, the ranges of variation in the Th/Yb and Th/Cr ratios appear to be relatively small in each group respectively. Even so, the ranges of variation are large enough in the case of the Buena Vista samples to prompt inquiry beyond the scope of this study. Methodologies for ceramic compositional analysis should not be limited to those used for chemical analyses alone. Valuable supplemental data is available from petrographic analysis supported by a knowledge of regional geology. Compositional analyses of ceramics are obviously interdisciplinary pursuits requiring specialized knowledge and ideally a collaborative effort in geology, mineralogy, and chemistry for archaeological interpretation (see Bishop, Rands, and Holley 1982). Keeping the latter in mind, further research may help to explain the ranges of chemical variation determined in this study. Further research objectives for the study of Buena Vista ceramic chemistry should include, but not be limited to, clay sourcing, comparative studies of regional ceramics, and the examination of probable trade networks. As more data are compiled, it may become possible to isolate chemical subgroups attributable to formal identification and, with the benefit of archaeological inference, dating for historical and anthropological interpretations.

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APPENDIX

FORTRAN PROGRAM FOR INAA

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      RESD-LIB/GEOCHEM/INAA7

0010C  THIS PROGRAM REDUCES INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS DATA TO
0020C  ELEMENT ABUNDANCES BY COMPARING SAMPLES TO A KNOWN CONCENTRATION IN A
0030C  STANDARD.  IT ALSO COMPUTES RELATIVE ERRORS BASED ON COUNTING STATISTICS.
0040C  PROGRAMMED: MARVIN H BEESON - CURTIS R KEEDY, REED COLLEGE, 1968
0050C  MODIFIED: ANSEL G JOHNSON - MICHAEL R MORAN, PORTLAND STATE UNIV. AUG 1975
0060C  MODIFIED:                  MICHAEL R MORAN, PORTLAND STATE UNIV. FEB 1977
0070C
0080C  PROGRAM IS IN 029 PUNCH CODE
0090C
0100C                                   EXPLANATION                          FORMAT
0110C
0115C   FIRST DATA CARD
0120C  II       NUMBER OF SPECTRA DETECTED                                    I2
0130C  JJ       NUMBER OF PEAKS PER SPECTRA                                   I2
0140C  NE       NUMBER OF ELEMENTS PER SPECTRA                                I2
0150C  NS       NUMBER OF SPECTRA TO BE EXCLUDED FROM SUMMARY TABLE           I2
0160C  EXPID    EXPERIMENT IDENTIFICATION                                     A72
0170C
0180C    SECOND DATA GROUP - STANDARD AND SAMPLE INFORMATION (LINE 51)
0190C                        2 DATA GROUPS PER CARD
0200C
0210C  NAME1    1ST HALF STANDARD OR SAMPLE IDENTIFICATION                     A4
0220C  NAME2 2ND HALF STANDARD OR SAMPLE IDENTIFICATION                       A4
0230C  **********                                                             2X
0240C  WT       WEIGHT OF SAMPLE OR STANDARD                                  F6.4
0250C  **********                                                             1X
0260C  CTD1     TIME IN DAYS TO START OF COUNTING AFTER IRRADIATION            F10.6
0270C  **********                                                             1X
0280C  DTM1     DETECTION TIME IN SECONDS                                     F7.0
0290C  **********                                                             1X
0300C
0310C           THIRD DATA CARD GROUP - ELEMENT INFORMATION (LINE 55)
0320C                     1 DATA GROUP PER CARD
0330C
0340C  NMPK     ELEMENT DETECTED, PEAK NAME                                   A4
0350C  **********                                                             2X
0360C  ISTD     LOCATION OF STANDARD AMONG ORDERED SAMPLES AND STANDARDS       I2
0370C  **********                                                             2X
0380C  CONC     ELEMENT CONCENTRATION IN STANDARD                             F9.2
0390C  **********                                                             2X
0400C  HLF      HALF-LIFE, IN DAYS, OF ISOTOPE BEING DETECTED                 F10.5
0410C  **********                                                             2X
0420C  UNITS    UNITS OF MEASURE FOR STANDARD                                 A4
0430C  **********                                                             2X
0440C  MP       NUMBER OF ELEMENT PEAKS TO BE AVERAGED IN SUMMARY TABLE       I1
0450C
0460C                          FOURTH DATA CARD GROUP  (LINE 57)
0470C                            5 DATA GROUPS PER CARD
0480C
0490C  NC1      NET COUNTS IN PEAK                                            F8.0
0500C  **********                                                             1X
0510C  ERR      NET ERROR FOR EACH PEAK                                       F4.1,1X
0520C
0530C
0540       REAL NAME1(45),NAME2(45),NMPK(30),LAM,NC,NC1(45)
0550       DIMENSION WT(45),CTD1(45),DTM1(45),ERR(45),EXPID(18)
0560       DIMENSION PPM(30,45),REL(30,45),PPM1(20,45),REL1(20,45),MP(30)
0570       READ(22,101)II,JJ,NE,NS,(EXPID(K),K=1,18)
0580   101 FORMAT(4I2,18A4)
0590       READ(22,102)(NAME1(I),NAME2(I),WT(I),CTD1(I),DTM1(I),I=1,II)
0600   102 FORMAT (2(2A4,2X,F6.4,1X,F10.6,1X,F7.0,1X))
0610       DO 2 I1=1,JJ
0620       J=1
```

```
0630       READ(22,103)NMPK(I1),ISTD,CONC,HLF,UNITS,MP(I1)
0640   103 FORMAT (A4,2X,I2,2X,F9.2,2X,F10.5,2X,A4,2X,I1)
0650       READ (22,104)(NC1(I),ERR(I),I=1,II)
0660   104 FORMAT(5(F8.0,1X,F4.1,1X))
0670       M=1
0680       DO3 I3=1,II
0690     4 CONTINUE
0700       I4=I3
0710       IF(J-1) 5,6,5
0720     6 I4=ISTD
0730       WTEMP=WT(I4)
0740       WRITE (6,105) (EXPID(ID),ID=1,18)
0750   105 FORMAT(1H1,18A4,/)
0760       WT(I4)=CONC
0770     5 NC=NC1(I4)
0780       ERR1=ERR(I4)/100
0790       DTM=DTM1(I4)/60
0800       CTD=CTD1(I4)
0810       STD=WT(I4)
0820       IF (NC-0.0) 300,10,1001
0830  1001 ACT=NC/DTM
0840       LAM=0.6931/HLF
0850       XLAM=EXP(-LAM*DTM*.00069444)
0860       CHI=(LAM*DTM*.00069444)/(1.0-XLAM)
0870       ACT1=ACT*CHI
0880       YLAM=EXP(-LAM*CTD)
0890       ACT0=ACT1/YLAM
0900       ERR1=ERR1*ERR1
0910       IF(J-1) 20,30,20
0920    30 STD=STD*WTEMP
0930       WT(I4)=WTEMP
0940       ACTS=ACT0/STD
0950       ERST=ERR1
0960       J=2
0970       WRITE(6,107)NAME1(I4),NAME2(I4),CONC,UNITS,HLF
0980   107 FORMAT(1X,2A4,1X,F12.4,1X,A4,2X,'    HLF = ',F10.5,/)
0990       WRITE (6,109)NMPK(I1),NMPK(I1)
1000   109 FORMAT (35X,A4,66X,A4,/)
1010       WRITE(6,108)UNITS,UNITS
1020   108 FORMAT(1X,'SAMPLE',6X,'WT',7X,'CTD',6X,'DTM'
1030&      ,6X,A4,8X,'ERR',21X,'SAMPLE',7X,A4,6X,'ERR',/)
1040       GO TO 4
1050    20 ABUN=ACT0/ACTS
1060       PPM(I1,I3)=ABUN/STD
1070       ERU=ERR1
1080       RL=SQRT(ERST+ERU)
1090       REL(I1,I3)=PPM(I1,I3)*RL
1100       WRITE(6,106)NAME1(I3),NAME2(I3),STD,CTD,DTM,PPM(I1,I3)
1110&      ,REL(I1,I3),NAME1(I3),NAME2(I3),PPM(11,I3),REL(I1,I3)
1120   106 FORMAT(1X,2A4,1X,F7.4,1X,F10.6,1X,F7.3,1X,F10.4,1X,F10.4,19X,2A4
1130&      ,1X,F8.2,1X,F8.2)
1140       GO TO 207
1150    10 WRITE (6,113)NAME1(I3),NAME2(I3),STD,CTD,DTM,NAME1(I3)
1160&      ,NAME2(I3)
1170   113 FORMAT(1X,2A4,1X,F7.4,1X,F10.6,1X,F7.3,7X,'N.D.',7X,
1180&      'N.D.',19X,2A4,5X,'N.D.',5X,'N.D.')
1190       PPM(11,I3)=0.0
1200       REL(I1,I3)=1.E10
1210   207 M=M+1
1220       IF(M.LE.5) GO TO 3
1230       WRITE(6,214)
1240       M=1
1250     3 CONTINUE
1260     2 CONTINUE
1270       II=II-NS
1280       J=1
1290       DO 230 K=1,NE
1300       NMPK(K)=NMPK(J)
1310       M=MP(J)
1320       IF (M-1)300,231,1010
1330  1010 IF (M-2) 300,233,1020
1340  1020 IF (M-3) 300,235,1030
1350  1030 IF (M-4) 300,237,300
1360   231 DO 232 I=1,II
1370       PPM1(K,I)=PPM(J,I)
1380       REL1(K,I)=REL(J,I)
1390       IF (PPM1(K,I)-0.0)300,1002,232
1400  1002 REL1(K,I)=0
1410   232 CONTINUE
1420       J=J+1
1430       GO TO 230
```

```
1440   233 DO 234 I=1,II
1450       PPM1(K,I)=(PPM(J,I)/REL(J,I)+PPM(J+1,I)/REL(J+1,I))/(1. /REL
1460&      (J,I)+1. /REL(J+1,I))
1470       REL1(K,I)=AMIN1(REL(J,I),REL(J+1,I))
1480       IF(PPM1(K,I)-0.0)300,1003,234
1490  1003 REL1(K,I)=0
1500    234 CONTINUE
1510       J=J+2
1520       GO TO 230
1530    235 DO 236 I=1,II
1540       PPM1(K,I)=(PPM(J,I)/REL(J,I)+PPM(J+1,I)/REL(J+1,I)+PPM(J+2,I)
1550&      /REL(J+2,I))/(1./REL(J,I)+1./REL(J+1,I)+1./REL(J+2,I))
1560       REL1(K,I)=AMIN1(REL(J,I),REL(J+1,I),REL(J+2,I))
1570       IF(PPM1(K,I)-0.0) 300,1004,236
1580  1004 REL1(K,I)=0
1590    236 CONTINUE
1600       J=J+3
1610       GO TO 230
1620    237 DO 238 I=1,II
1630       PPM1(K,I)=(PPM(J,I)/REL(J,I)+PPM(J+1,I)/REL(J+1,I)+PPM(J+2,I)
1640&      /REL(J+2,I)+PPM(J+3,I)/REL(J+3,I))/(1./REL(J,I)+1./REL
1650&      (J+1,I)+1./REL(J+2,I)+1./REL(J+3,I))
1660       REL1(K,I)=AMIN1(REL(J,I),REL(J+1,I),REL(J+2,I),REL(J+3,I))
1670       IF (PPM1(K,I)-0.0)300,1005,238
1680  1005 REL1(K,I)=0
1690    238 CONTINUE
1700       J=J+4
1710    230 CONTINUE
1720       DO 250 K=1,NE
1730       DO 251 I=1,II
1740       IF(PPM1(K,I)-0.0) 300,251,1006
1750  1006 P=.02
1760       N=0
1770    204 N=N+1
1780       IF(N.GT.7)GO TO 300
1790       P=P*10
1800       IF(REL1(K,I)-P)208,1007,1007
1810  1007 GO TO 204
1820    208 DECPL=10.**(N-3)
1830       REL1(K,I)=FLOAT(IFIX((REL1(K,I)+5.*10.**(N-4))/DECPL))*DECPL
1840       PPM1(K,I)=FLOAT(IFIX((PPM1(K,I)+5.*10.**(N-4))/DECPL))*DECPL
1850    251 CONTINUE
1860    250 CONTINUE
1870       K=1
1880       L=7
1890    212 WRITE (6,226)EXPID
1900    226 FORMAT(1H1,////,1X,18A4,/)
1910       IF(L.GT.NE)L=NE
1920       WRITE (6,213)(NMPK(I),I=K,L)
1930    213 FORMAT (1X,'SAMPLE',10X,7(A2,14X))
1940       WRITE(6,214)
1950    214 FORMAT(1H )
1960       M=1
1970       N=5
1980    215 IF(N.GT.II)N=II
1990       DO 210 I=M,N
2000    210 WRITE(6,224)NAME1(I),NAME2(I),(PPM1(J,I),REL1(J,I),J=K,L)
2010    224 FORMAT (1X,2A4,7(2(1X,F7.2)))
2020       WRITE(6,214)
2030       M=M+5
2040       N=N+5
2050       IF(M.LE.II)GO TO 215
2060       K=K+7
2070       L=L+7
2080       IF(K.GT.NE)GO TO 206
2090       GO TO 212
2100    206 WRITE(6,209)
2110    209 FORMAT(1H1)
2120    300 CONTINUE
2130       STOP
2140       END
```